

DC Conversion Equipment Connected to the Medium-Voltage Grid for Extreme Fast Charging Utilizing Modular and Interoperable Architecture

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2020 DOE Vehicle Technologies Office Annual Merit Review
Presentation

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EPRI

Project ID: elt 236

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Overview

Timeline

- Project start date: Oct 2018
- Project end date: July 2022
- Percent complete: 20%

Relevance to DOE Established Barrier

- Enabling Technologies - Establishing a foundational system for DC connected EV-charging that integrates with devices such as distributed energy resources, solar, wind and energy storage.

Budget

- Total project funding
 - DOE share: \$2,601,500
 - Contractor share: \$2,601,500
- Funding for FY 2019: \$293,994

Partners

- EPRI – Project Lead
- Eaton Corporation
- Tritium
- NREL
- ANL
- North Carolina State University

Relevance

Overall Objective

- Develop and demonstrate medium voltage Silicon Carbide (SiC) -based AC-DC conversion equipment and the DC-to-DC head unit for use in extreme fast charging (XFC) equipment capable of simultaneously charging multiple light duty plug-in electric vehicles (PEV)s at rates of ≥ 350 kW and a combined power level of ≥ 1 MW while minimizing the impact on the grid and operational costs.

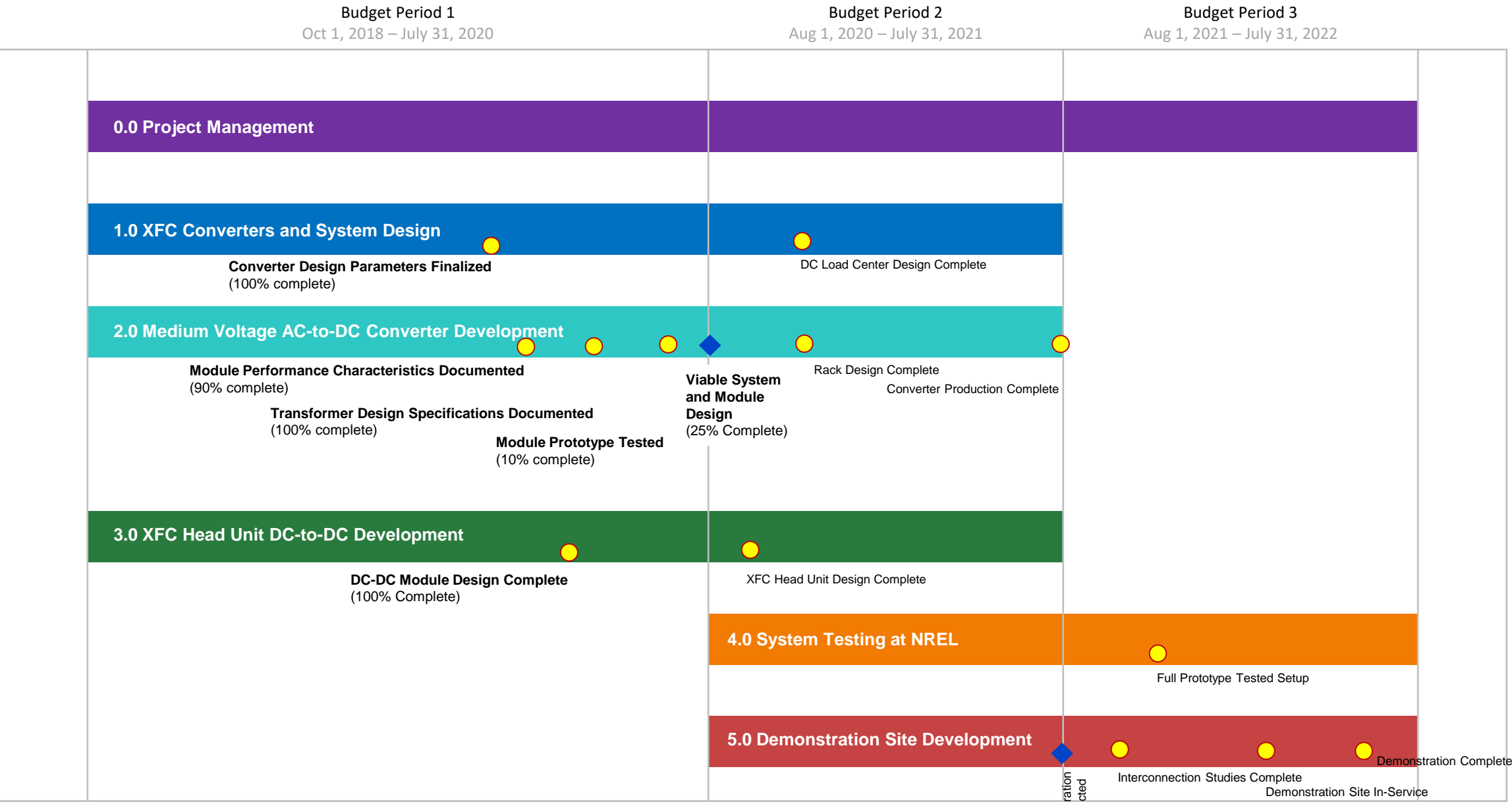
Relevance to DOE's Grid and Charging Infrastructure Program Goals

- Extreme Fast Charging – Develops and tests Direct Current technologies for Extreme Fast Charging while minimizing impacts to the grid. Research could be serve to identify opportunities for interoperability and technical transfer activities.
- EV Grid Integration and Services – Direct Current technologies could facilitate the integration of distributed energy resource to minimize the impact on the grid.

Potential Impacts (project will investigate these aspects)

- Reduce the Total Cost of Ownership (including Demand Charges) for XFC site hosts and utilities
- Improve efficiency and reduce losses
- Reduce footprint of equipment
- Provide a single point of grid integration for distributed energy resources
- Provide new capabilities for grid integration (power factor correction, VAR compensation, disturbance isolation, ...)
- Optimization of equipment sizing for upstream power supplies that serve XFC equipment

Milestones



● Milestone ◆ Go/No-Go

Approach

Project Teaming Strategy

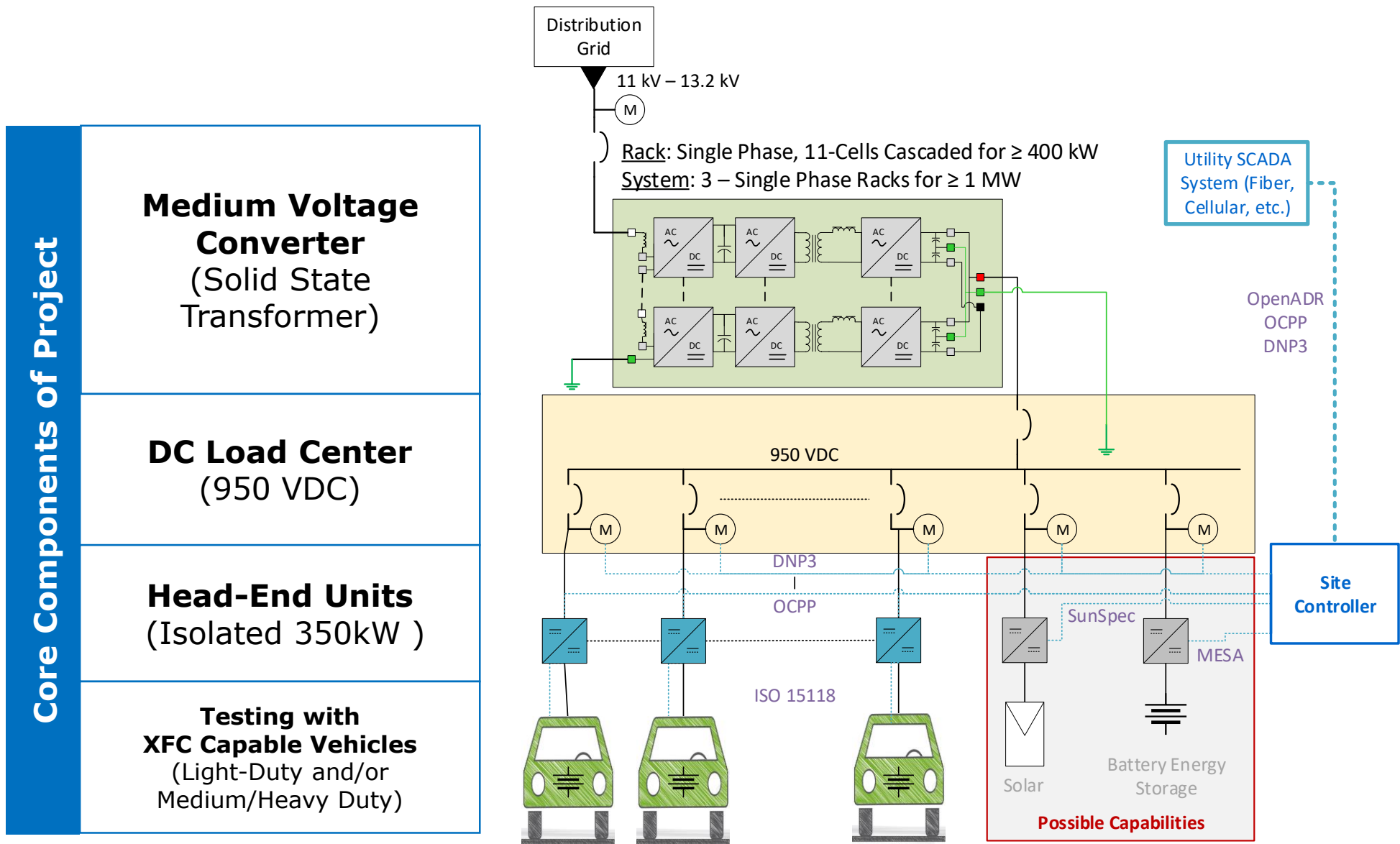
- Power Electronics - System specifications determined collaboratively, while the development of the two major power electronics pieces are designed by suppliers focused on the two different businesses
 - Eaton is leading the work on the Medium Voltage AC to DC converters
 - Tritium is leading the work on the DC to DC converters
- Testing - Three levels of testing included in project
 - Component level testing and end-of-line production testing performed by respective manufacturer
 - System testing to occur at NREL laboratory with simulated and actual vehicles
 - Demonstration site testing in collaboration with host utility with actual vehicles
- Vehicles - Supporting automakers (Hyundai America Technical Center and Fiat Chrysler Automobiles) are included in project to support testing. If vehicles capable of charging at 350kW and above are unavailable for testing from supporting automakers, EPRI will identify and obtain vehicles from other vehicle manufacturers.
- Demonstration Site - EPRI has more the three supporting utilities interested in hosting the demonstration site. The decision on the actual demonstration site will be based on specific site characteristics identified by the utilities, anticipated vehicle charging to occur at site and the site development budget.

Unique Aspects of Work (beyond the barriers described in “Relevance” slide # 3)

- Pathway to Commercialization - Seeking to develop equipment, standards and techniques that exhibit possible pathways to commercialization
- Interoperability - Seeking to develop system that is capable of operating with power conversion equipment and head end units from multiple manufacturers
- Technology Transfer - EPRI will be collaborating with industry participants throughout the project process
- Diverse Project Team - Project partners from various perspectives (utilities, hardware manufactures, automotive manufacturers, national laboratories, and university)

Technical Accomplishments and Progress

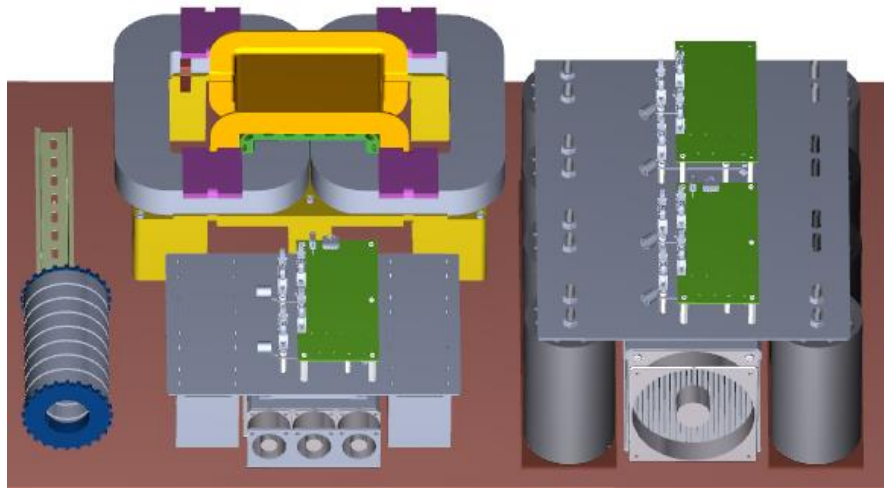
Target Design & System Level Capabilities



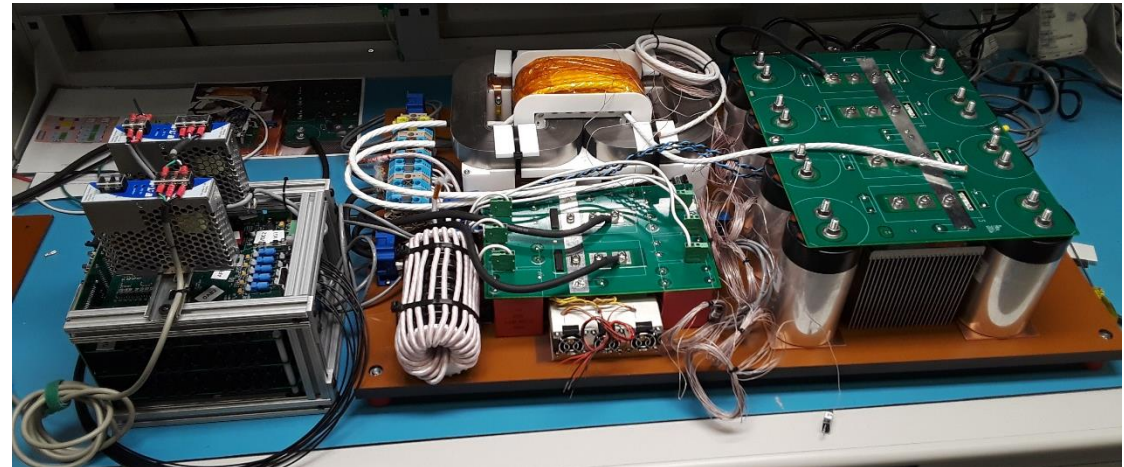
Technical Accomplishments and Progress

Medium Voltage Converter Topology

- Medium Voltage Converter Rack: will be composed of multiple cells for a power rating $\geq 400\text{kW}$
 - Eleven cells will be configured in a single-phase cascade design to bridge the 7.6 / 13.2 kV utility connection
 - Each cell has a power rating of 40kW
 - The cells will be connected in parallel on the DC side of the converter
- Medium Voltage Converter System: will be composed of three single phase racks for a power rating $\geq 1\text{MW}$
- Status:
 - Prototype power cells are in assembly, image below
 - Cell level testing and multi-cell testing to follow, starting with 3 cell cascading systems at 2.4kV



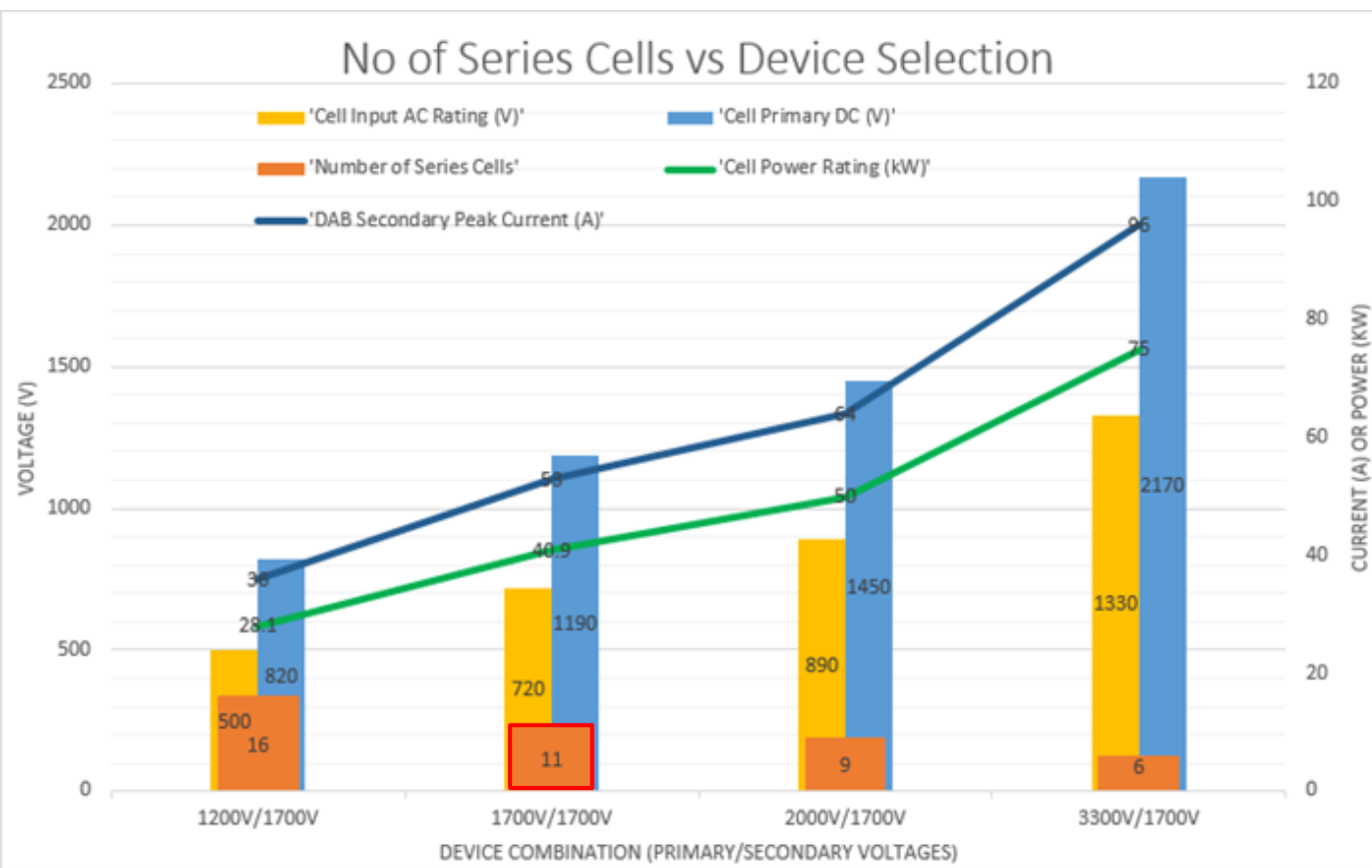
CAD model of a single cell



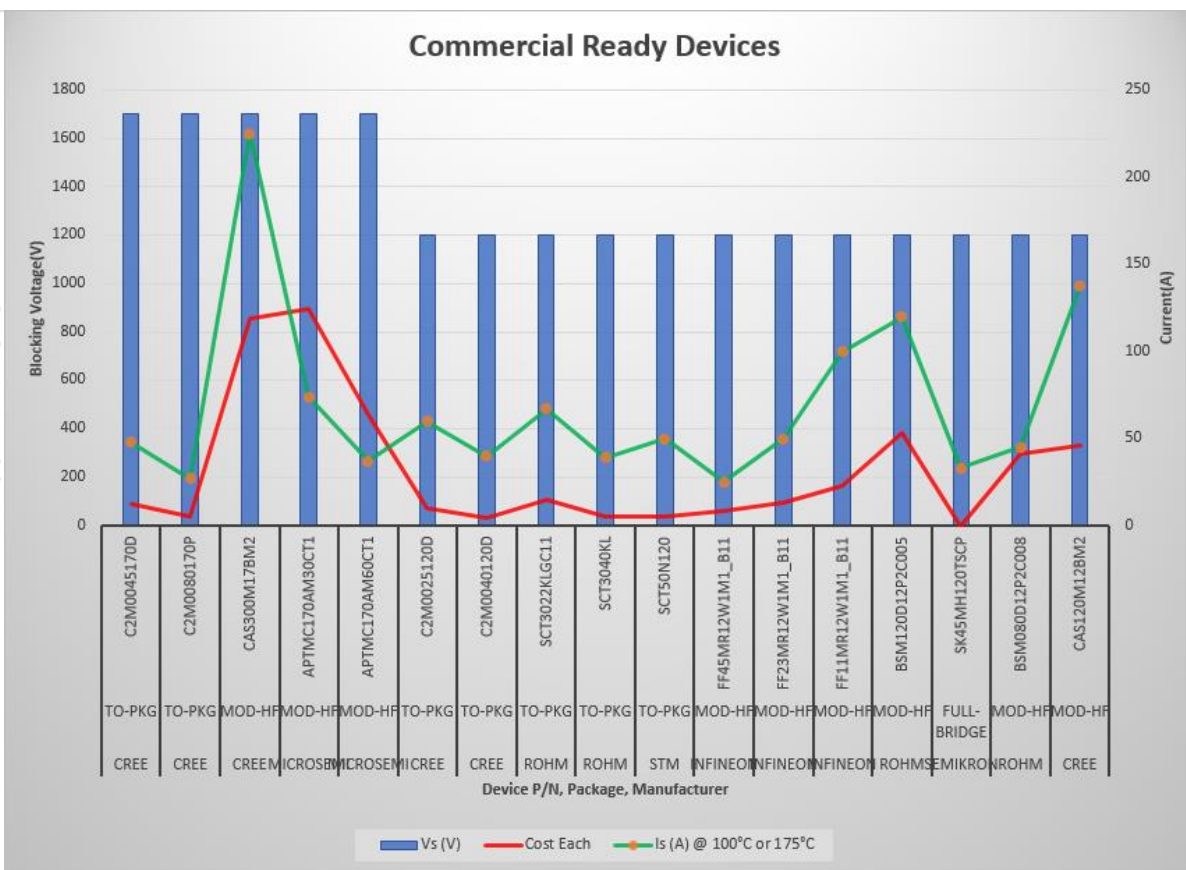
Single cell assembly in progress

Technical Accomplishments and Progress

Modeling and Trade-off Analysis



Selecting voltage rating of power devices based on number of cascaded cells required.



2019 commercially available Silicon Carbide chips in the market

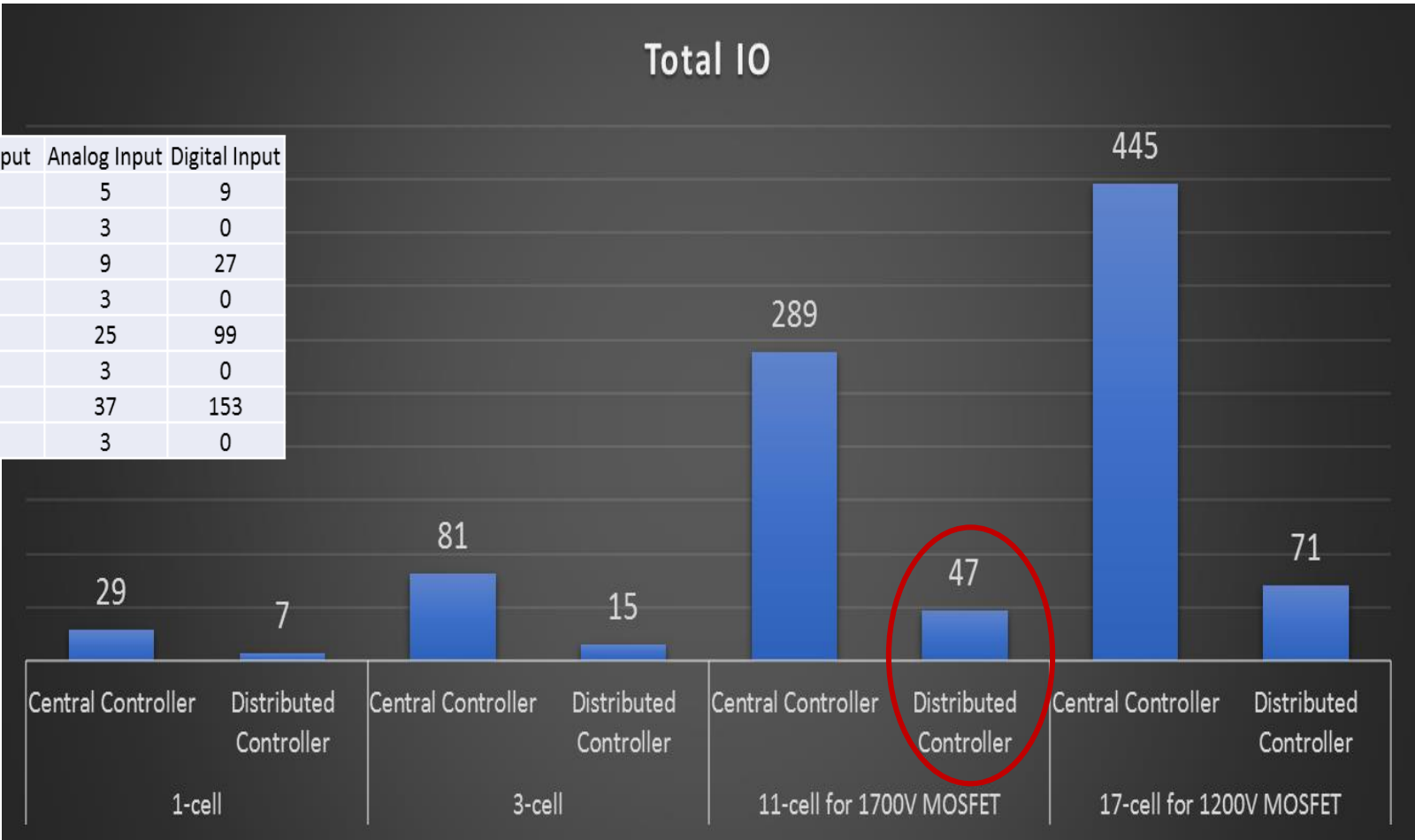
Technical Accomplishments and Progress

Modeling and Controller Design

Device voltage drives the number of cells and this drives number I/O to be managed by the controllers

Number of Cells	Topology	Total IO	Digital Output	Analog Input	Digital Input
1-cell	Central Controller	29	15	5	9
	Distributed Controller	7	4	3	0
3-cell	Central Controller	81	45	9	27
	Distributed Controller	15	12	3	0
11-cell for 1700V MOSFET	Central Controller	289	165	25	99
	Distributed Controller	47	44	3	0
17-cell for 1200V MOSFET	Central Controller	445	255	37	153
	Distributed Controller	71	68	3	0

Control strategy decision drivers



Technical Accomplishments and Progress

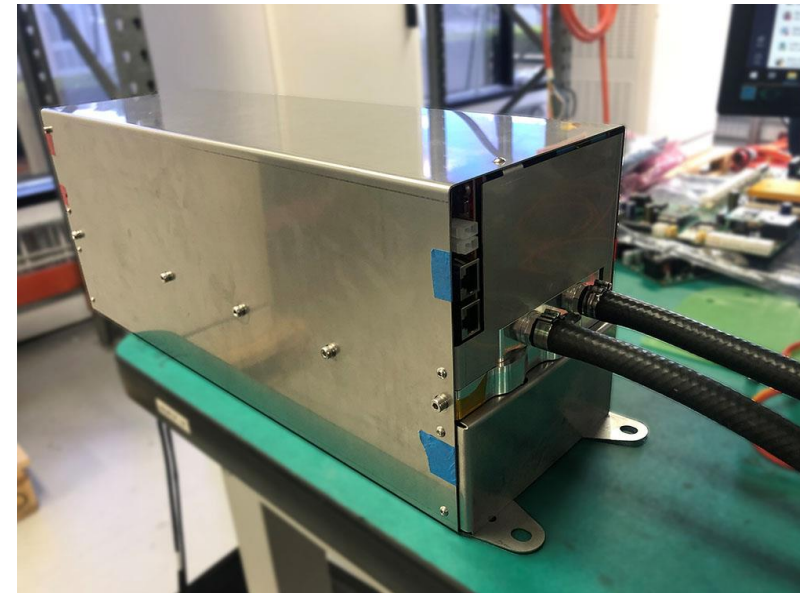
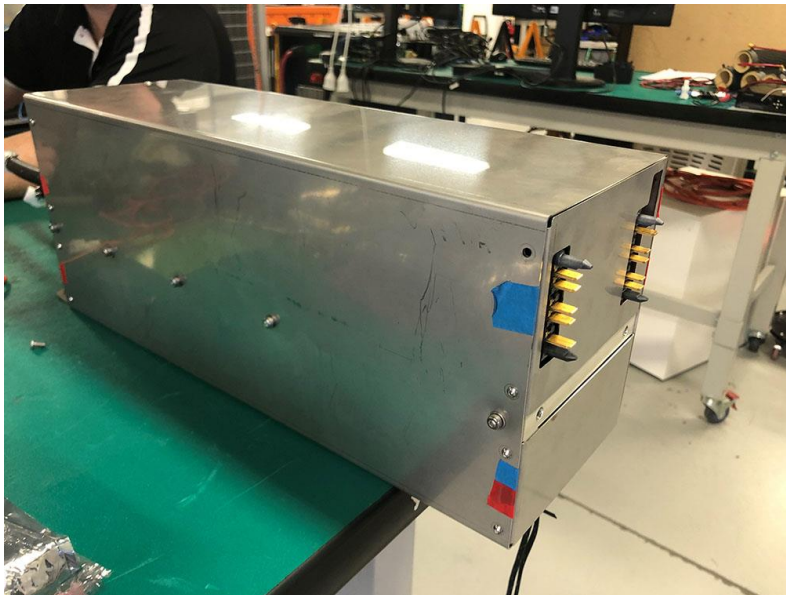
Head-End Unit

Head-End Unit Will Now Utilize an Isolated Converter

- Project shift to DC distribution requires isolated DC-to-DC Head-End unit to be developed and beyond original project scope
 - Previously, the Head-End unit was to be a modification of Tritium's existing 350kW non-isolated head unit with a switched matrix DC distribution
- Tritium's updated project scope, with new isolated DC-to-DC power electronics modules, not expected to impact project schedule

Status of New Isolated Modules for Head-End Converter

- Tritium has now completed development on a 25kW isolated DC-to-DC module, and has validated this design in extensive in-house laboratory testing, including with multiple modules running synchronised and in parallel, eliminating this large technical risk from the overall project
- 14 cells connected in parallel to achieve 350kW
- Prototype liquid-cooled, isolated, 25kW modules, shown below, are approximately 200mm x 150 mm x 400mm



Technical Accomplishments and Progress

950V DC Distribution

Performance Specifications

- Nominal 950Vdc, steady-state output within 940Vdc to 960Vdc, 10V/s slew under load
- Center grounded output, $\pm 475\text{V}$ with respect to Earth, for a “950V” DC bus
- Ripple max $\pm 20\text{V}$ for 0 – 400Hz, preferable at $\pm 10\text{V}$
- Dynamic regulation, overcurrent protection, precharging, discharge, y-capacitance and leakage requirements defined

Implications Of Specifications

- Will be using commercially available / commodity wiring with insulation below 600V
- Power electronics will have protection setting that can be utilized to support protection coordination
- Based on review of DC protection / isolation devices, expect to utilize commercially available fusing/contactors or breakers for connections to the DC bus



Rated operational current rated = uninterrupted current $I_n = I_u$ A	Short-circuit protective device fuse gR-characteristic A	Screw connection	1000VDC Fixed mounted Designation Article No.	1500VDC Fixed mounted Designation Article No.
800	-	S	N4-4-800-S1-PV-NA 179325	N4-4-800-S15-PV-NA 179328
1000	-	S	N4-4-1000-S1-PV-NA 179326	N4-4-1000-S15-PV-NA 179329
1100	-	S	N4-4-1100-S1-PV-NA 179591	N4-4-1100-S15-PV-NA 179592
1200	-	S	N4-4-1200-S1-PV-NA 179327	N4-4-1200-S15-PV-NA 179330



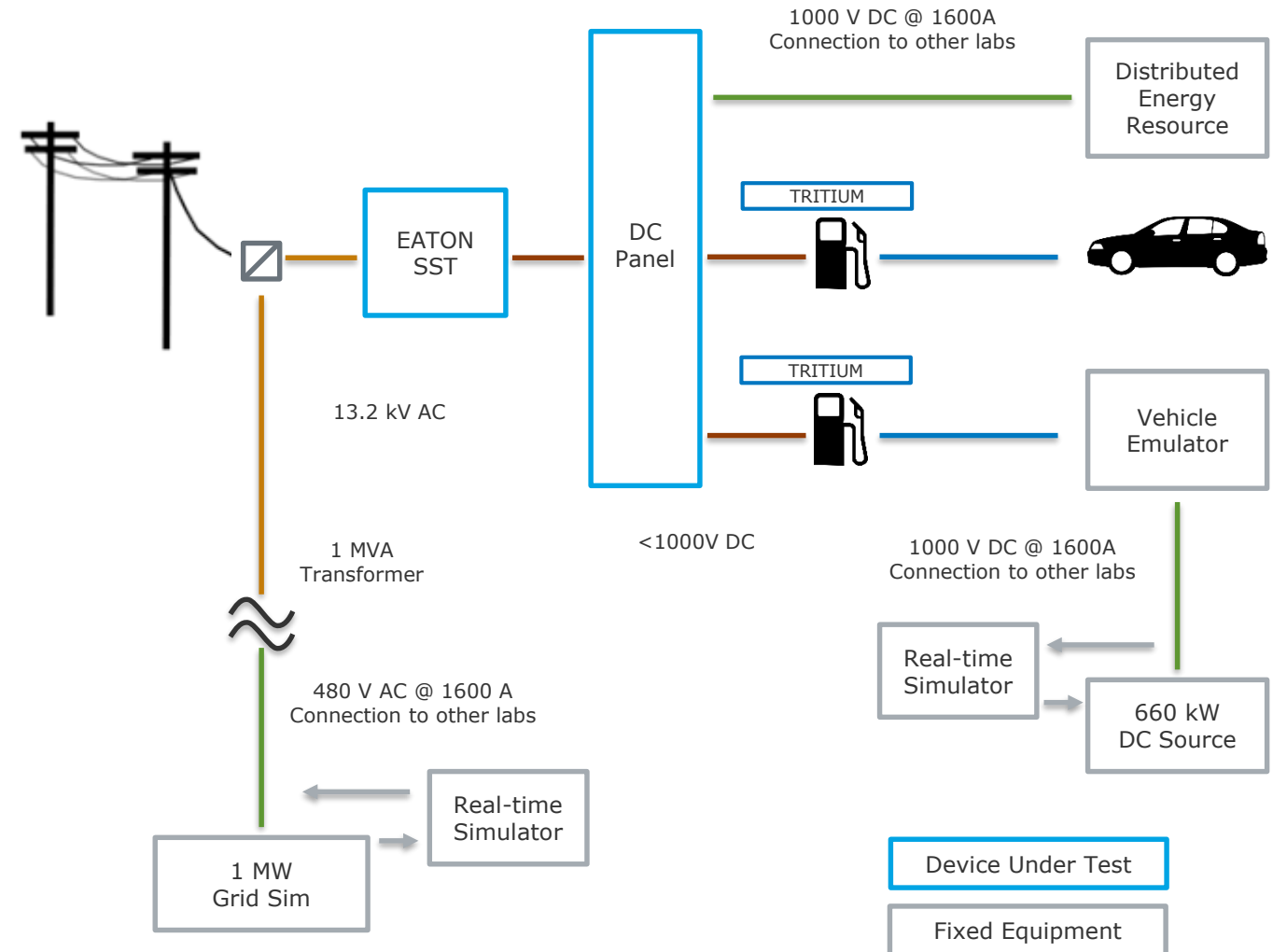
Rated operational current rated = uninterrupted current $I_n = I_u$ A	Short-circuit protective device fuse gR-characteristic A	Screw connection	1000VDC Fixed mounted Designation Article No.	1500VDC Fixed mounted Designation Article No.
160	200	S	N2-4-160-S1-DC 127732	N2-4-160-S15-DC 167688
200	200	S	N2-4-200-S1-DC 127733	N2-4-200-S15-DC 167689
250	200	S	N2-4-250-S1-DC 154940	N2-4-250-S15-DC 167690

Technical Accomplishments and Progress

Vehicle Emulation and Testing at NREL

Support the evaluation of the complete XFC charging system in preparation for deployment at the utility demonstration site.

- System Performance
 - XFC vehicle charging
 - Conversion efficiency
 - DC micro-grid integration
- IEEE 1547 Interconnection
 - Voltage ramps /steps
 - Frequency ramps/ steps
 - Unintentional islanding
 - Power quality
- IEEE 519 Harmonics
 - Voltage / Current harmonics



Technical Accomplishments and Progress

Field Demonstration – Initial Thoughts

Considerations

- Multiple sites are currently under consideration, from the listed utility collaborators involved in the project
- Several of the potential demonstration sites also include vehicle collaborators
- The potential demonstration sites serve different vehicle classes, from light-duty, bus, heavy-duty truck or a combination of vehicle classes.

Process






- Project team to complete selection of demonstration site(s) in Budget Period 2
- A variety of factors will go into the final decision of demonstration site(s) including; utility distribution connection considerations, level of utility support, availability of XFC compatible vehicles at the site, construction costs, budget and other factors
- A go / no-go decision will occur at the end of Budget Period 2 based on completion of the demonstration site(s) selection process

Responses to Previous Year Reviewers' Comments

- *This is a new project, therefore it was not reviewed last year*

Collaboration and Coordination with Other Institutions

Project Team

	Prime – Leading DC load center design, DC microgrid controls and demonstration site development
	Subrecipient – Leading Medium voltage AC to DC converter design and production
	Subrecipient – Leading head unit DC to DC converter design and production
	Subrecipient – Leading laboratory testing of XFC system
	Subrecipient – Leading DC metering activities

Key Utility Collaborators

University Collaborator



Other Collaborative Activities

<ul style="list-style-type: none">• EPRI’s Infrastructure Working Council• US DRIVE• DOE multi-lab Multi-port 1 + MW Charging System for Medium- and Heavy-duty Electric Vehicles effort• California’s Electric Program Investment Charge Program
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Remaining Challenges and Barriers

The project team has identified certain challenges going forward that will be closely monitored with mitigation plans for key challenges

Technology

- Performance of the initial cell and module testing at Eaton's facility may not meet modeled results or other criteria (Low probability, Medium Impact)
- Development of an isolated XFC dispenser with a 950V DC supply may encounter integration challenges (Low probability, Medium Impact)
- γ -capacitance issues may be problematic for stable operations, protection and safety of system (Low probability, Medium Impact)
- Unexpected problems may be discovered during testing at NREL's laboratory (Medium probability, Medium Impact)

Technology Transfer

- Lack of consensus of interoperability approaches, common understanding of DC topologies, equipment options and communications systems for the DC bus (Medium probability, Low Impact)
- Implementation of communication protocols. Which ones are appropriate, which ones are implemented vs standard being defined (Medium probability, Low Impact)

Other

- Covid-9 related impacts on supply chain, key resources or organizations (Medium probability, Medium Impact)

Proposed Future Research

FY 2020 Work

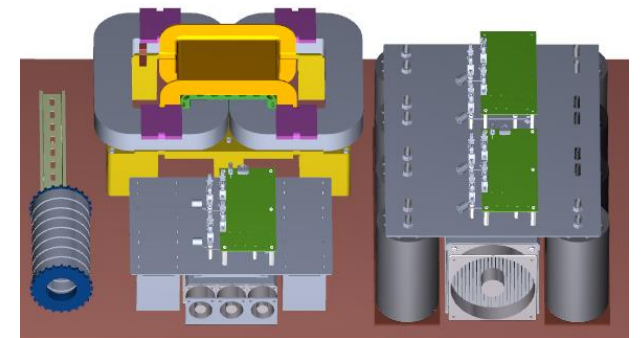
- 1.0 XFC Converters and System Design
 - Electrical design of 950 v DC load center and controls
- 2.0 Medium Voltage AC-to-DC Converter Development
 - Integrate power cells into rack design
 - Test system components and develop plans to produce converter
- 3.0 XFC Head Unit DC-to-DC Development
 - Integrate power cells into head-end unit
 - Test system components and develop plans to produce converter
- 4.0 System Testing at NREL
 - Develop test plan

FY 2021 Work

- 1.0 XFC Converters and System Design
 - DC metering
- 2.0 Medium Voltage AC-to-DC Converter Development
 - Procure components and produce converters
- 3.0 XFC Head Unit DC-to-DC Development
 - Procure components and produce converters
- 4.0 System Testing at NREL
 - Conduct system performance and efficiency tests
 - Conduct grid integration tests
 - Conduct testing with XFC capable vehicles
- 5.0 Demonstration Site Development
 - Site planning and interconnection studies
 - Prepare site

Research Opportunities Beyond Objectives of Current Project

- Additional integration testing of DC microgrid with medium voltage converters
- Testing of hybrid plants within a DC microgrid
- Dynamic response of multi-level converters to unexpected system conditions
- Failure mode analysis, response to blackstart, shut-down, and other low probability / high impact events
- Reliability and resiliency monitoring of the DC infrastructure



Summary

- Prototypes of the power cells in the Medium Voltage Converter and modules in the Head-End Unit are at advanced stages
- High level interest in DC distribution for DC fast charging exists within the utility industry and with other organizations associated with vehicle electrification
- Technology transfer objectives will be a driving objective of the project
- The application of medium voltage connected DC conversion equipment may also be useful for other electric vehicle DC fast charging power levels and for integration of distributed energy resources, especially if it's able to reduce infrastructure space requirements

Technical Back-Up Slides

Technical Back-Up (if needed)